Multi-period variations during Solar Cycles 23–24

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Abstract

Solar periodicity is discovered in many magnetic activity indices (11 years, Rieger type 155-165 days, hundreds, and thousands of years). This research investigates multi-periodic variations in solar activity during Solar Cycles 23–24 and estimates the dynamo field strength. Daily sunspot area data from the Greenwich Royal Observatory were analyzed using Lomb-Scargle and Wavelet methods. These reveal multi-periodic variations (40–600 days) across the Sun's full disk. The observed periods likely originate from magneto-Rossby waves in the solar dynamo layer. We estimate dynamo field strengths of 25–31 kG for Cycle 23 and 23–30 kG for Cycle 24 using wave dispersion relations.

Keywords: *asolar cycles; periodicity; sunspot activity; magneto-Rossby waves*

1. Introduction

The Sun is a quite active star and we can observe different activity indices in its surface (faculae, prominences, sun flares, and sunspots). The activity of the Sun is mainly due to its dynamo magnetic field and the activity has a periodic character. The main periodicity characterised 11 years, which is called the Schwabe cycle (Schwabe, 1844). This periodicity is seen in the analysis of various data during all cycles. The mechanism of cycle generation is still not fully understood, but a large-scale dynamo is believed to be behind the activity. The dynamo layer is probably located between the radiative and convective envelopes (the tachocline), where a toroidal magnetic field is generated. In addition to the Schwabe cycle, there are longer periods of activity, such as hundreds and thousands of years. On the other hand, there are shorter period variations with a period of 155-165 days known as Rieger-type periods (Carbonell & Ballester, 1990, Lean & Brueckner, 1989, Oliver & Ballester, 1994, Rieger et al., 1984). This periodicity was discovered in γ-ray flares and afterward has been learned in many indices of the sun activity. The Rieger periodicity can be explained in terms of unstable magneto-Rossby waves in the tachocline (Zaqarashvili et al., 2010a). Furthermore, we found the quasi-biennial oscillation and this activity occurs over 2 years (McIntosh et al., 2015, Zaqarashvili et al., 2010b). According to the first idea, a double dynamo model, functioning across two dynamo layers, may be able to explain the quasi-biennial oscillations. One operates below the convection zone and the other near the surface. In the following opinion, instability of magneto-Rossby waves in the tachocline can clarify it (Zaqarashvili et al., 2010b). Preliminary analysis showed that besides the Rieger period, there are variations in solar activity shorter between 40 to 100 days and longer (200-600 days). This issue is not studied very well and this research could answer some question about dynamo models. we analyse data of the sunspot areas during cycle 23-24 to estimate shorter and longer periods than is the Rieger-type period for the hemispheres and the full disk.

2. Data

To study the periodicities, we used a solar activity database. Greenwich Royal Observatory (GRO) daily and monthly sunspot area USAF/NOAA data for full disk, which are available for 1874–2016. We use statistical methods: Wavelet and Lomb-Scargle. This allowed us to use the wavelet statistical method for data from cycles 23 and 24 and identify localized periodicity during this cycle (ranging from 40 to 600

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days). Lomb-Scargle helps us to determine the exact periodicity. We compared the results of the analysis of the full disk data for each cycle (23 and 24). Using the obtained periods, we estimate the magnetic field strength using the dispersion ratio of magneto-Rossby waves.

2.1. Cycle 23-24

The multi-periodic variations were revealed by the analysis of data during Sun cycle 23 (Fig.1). There are some strong periodicities. The full data analysis identified periodicities of 43, 65 and 83 days. Additionally, the analysis revealed longer-term periodicities, including the well-known Rieger-type periodicity (160 days), as well as a shorter periodicity around 115–120 days. These results are consistent with the research of Gurgenashvili et al. (2021). Multi-periods variations between from 200 to 600 days indicate in the full disk data analysis. During Solar Cycle 23, the southern hemisphere was characterized by multiple periodicities. The Lomb-Scargle periodogram revealed multiple significant peaks in this long-period range, particularly near 260, 310, 375 days, indicating complex long-term modulations in solar activity.

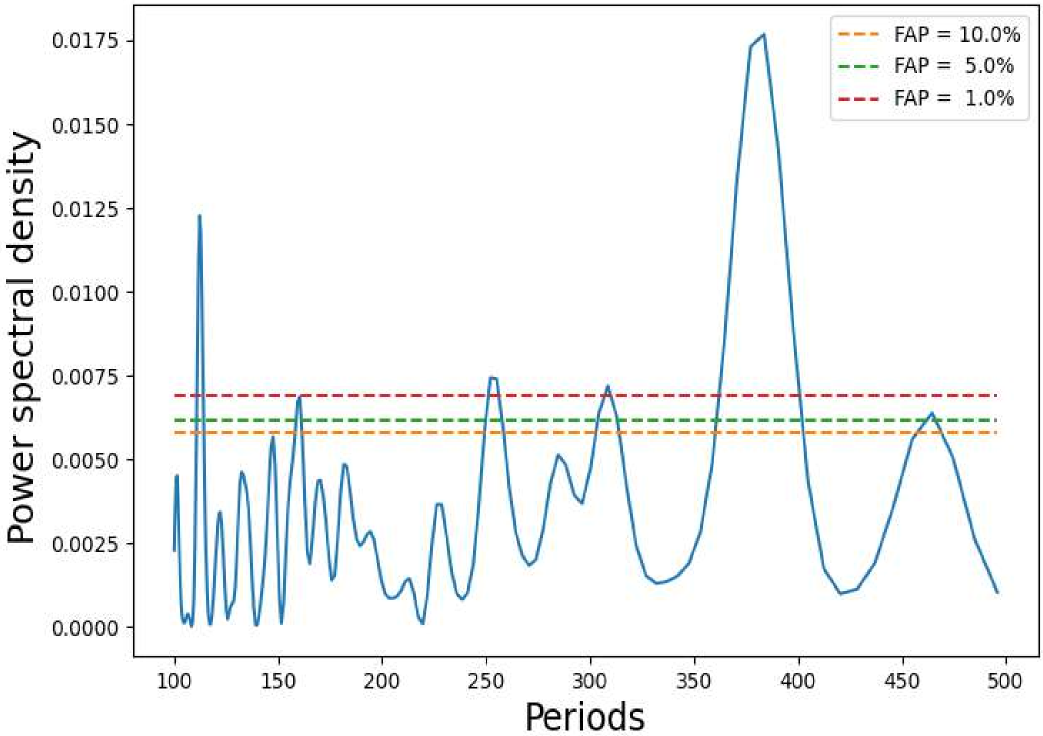

Figure 1. Lomb-Scargle periodogram of sunspot areas during Solar Cycle 23. The plot shows the power spectral density as a function of period, highlighting dominant periodicities in the dataset. Horizontal dashed lines indicate false alarm probability (FAP) levels of 10%, 5%, and 1%, representing the statistical significance of the detected peaks.

GEO displays several variations in the Solar 24 cycle. Lomb-Scargle periodogram of the full disk data of sunspot area shows strong periods, 48 and 60 days, also the weaker oscillation is 93 days 2. There are some stronger peaks than is Rieger type period. Data analysis of the full disk displays multiperiods: 140, 190, 285, 390 days(Fig.2). The stronger period is 285 days than Rieger type period 190 day.

Periods longer than the Rieger period appear to correlate with the overall strength of the solar cycle. During the stronger Solar Cycle 23, a 265-day periodicity is observed, whereas in the weaker Solar Cycle 24, a 285-day period emerges. Similarly, a 375-day periodicity is detected in Cycle 23, while Cycle 24 exhibits a 390-day period, both showing a correlation with cycle strength. Furthermore, shorter periods appear to converge, suggesting the need for further investigation of the underlying mechanisms responsible for this behavior.

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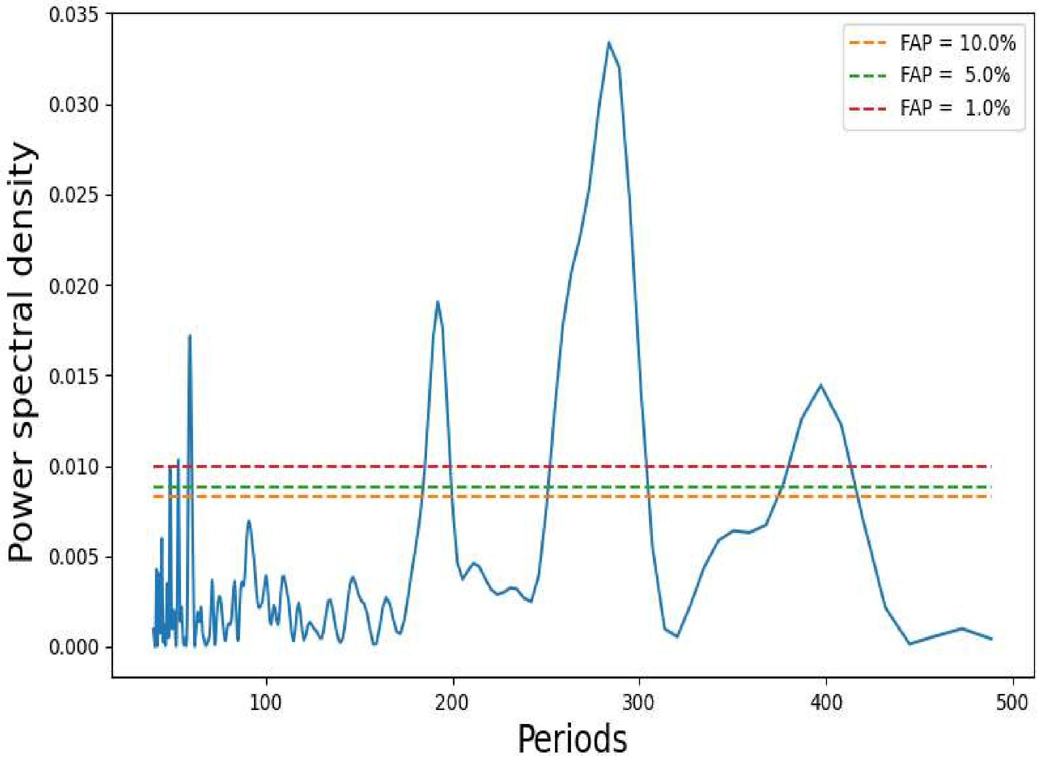

Figure 2. Lomb-Scargle periodogram of sunspot areas during Solar Cycle 24. The plot shows the power spectral density as a function of period, highlighting dominant periodicities in the dataset. Horizontal dashed lines indicate false alarm probability (FAP) levels of 10%, 5%, and 1%, representing the statistical significance of the detected peaks.

3. Discussion and Conclusion

Nowadays the mechanism of solar activity is unsolved problem and it is studding subject in solar physics. Supposedly,the periodicity caused by large-scale dynamo action in the solar interior. If the solar activity is a feature of the dynamo layer, then it should carry information about its physical parameters.

In this study, we analysed the periodicities in sunspot area data during Solar Cycles 23 and 24, focusing on the full-disk observations. Using the identified periodicities and applying the dispersion relation of magneto-Rossby waves, we estimated the strength of the dynamo magnetic field for both cycles.

The equation has two solutions: one for fast waves and one for slow waves. Fast waves may lead to short-term variation (Gurgenashvili et al., 2016), while slow magnetic Rossby waves may contribute to the long-term periodicity of the solar cycle (Zaqarashvili et al., 2015).

$$\omega_{nm} = -\frac{m\Omega}{n(n+1)}\left(1 \pm \sqrt{1 - \frac{v_A^2 n(n+1)}{\Omega^2 R^2}\left(2 - n(n+1)\right)}\right) \tag{1}$$

Where ω is the frequency of fast and slow magneto Rossby waves, Ω is the equatorial angular velocity, ρ is the density, R is the distance from the solar center to the dynamo layer, and m and n are toroidal and poloidal sperical harmonics. The magnetic field stranght is unknow. We use the studied periods and to estimate stranght of the dynamo magnetic field. In cycle 23 stranght is between 25-31 KG,while in cycle 24, it is lower, ranging from 23-30 KG.

Zaqarashvili et al. (2015) demonstrated that slow magnetic Rossby waves can lead to long-periodicity during the solar cycle, while short periods, such as the Rieger period, can be explained through the dispersion relation of fast magnetic Rossby waves. To explain our periods, we will use both findings within the 100-600 days interval. The Rieger period is explained by a specific harmonic, m=1 and n=4, while the obtained periods are described through other harmonics (m=1 and n=1, 2, 3, 4, 5).

Overall, this study confirms that multi-periodic variations in solar activity can serve as a diagnostic tool for estimating the magnetic field strength in the solar dynamo region. The results from the full-disk data

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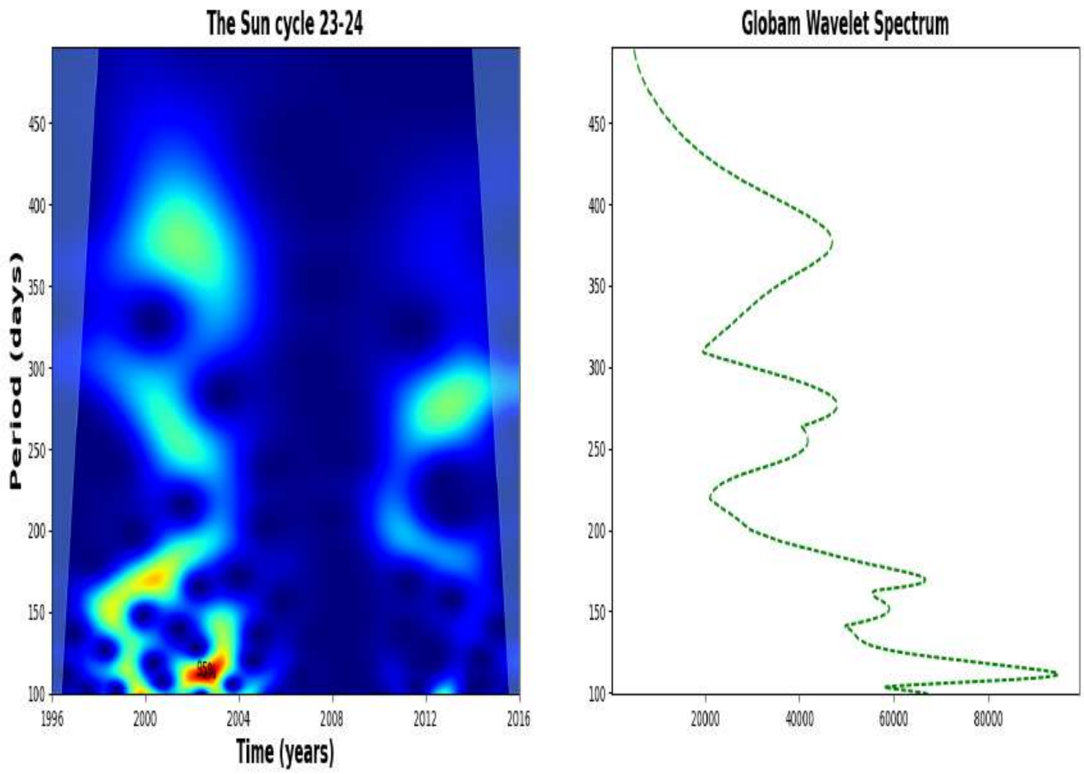

Figure 3. Wavelet analysis of sunspot areas during Solar Cycles 23–24. The left panel shows the wavelet power spectrum as a function of time (1996–2016) and period (in days), revealing the temporal evolution of dominant periodicities. The cone of influence is shown as the shaded region, indicating where edge effects become significant. The right panel presents the global wavelet spectrum, which is the time-averaged wavelet power across the entire time series.

analysis support the theoretical interpretation involving magneto-Rossby waves and highlight the complex nature of solar magnetic variability over different timescales.

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